ASSESSING AVIATION MAINTENANCE WORK ENVIRONMENTS AND WORKER REST

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EXECUTIVE SUMMARY

This paper summarizes selected environmental conditions of the aviation maintenance workplace and the amount of sleep obtained by aviation maintenance personnel as reported in Johnson, et al. 2001. One hundred technicians from three large carriers wore measurement devices to monitor temperature, lighting, and sound levels while working. In addition, the research measured sleep conditions, assessed over a 2-week, 24-hour/day duration. Results showed summer temperature average of 86^{o}F (30^{o}C) with ranges from 59^{o}F (15^{o}C) to 130^{o}F (54C). Approximate average daily sleep duration for maintenance personnel was 5 hours. Five hundred airline maintenance personnel responded to a questionnaire about fatigue and work conditions. This data collection phase sets the stage for a continuing effort to search for a relationship between fatigue and error.

1.0 MEASURING WORK CONDITIONS AND FATIGUE: ACTIVITY TO DATE

The initial phase of this current phased-study commenced in 1998 (Bosley, Miller, & Watson). That study completed an excellent literature review and analysis of workplace factors and fatigue in maintenance environments. Bosley et al.'s study identified and tested equipment to collect environmental and sleep data in maintenance environments. Bosely et al. selected equipment manufactured by the Mini Mitter Corporation to collect the data in a relatively unobtrusive manner. The Mini-Logger, slightly larger than a pack of cigarettes, collects continuous data on time, temperature, sound level, and light. Volunteers wore the Mini-Logger, in their front pocket during work hours. The Actiwatch was worn at all times, 7 days a week, 24 hours a day. Researchers have found the Actiwatch to be as accurate as the most sophisticated measurement equipment used in sleep research (Kushida, et. al., In press). The Actiwatch, most importantly, accurately measures when the wearer is asleep. Bosley et al.'s early testing showed that the devices are accurate and reasonably durable. They are also acceptable to the user, and capable of collecting extensive "real-world" data.

Dr. Bosley and colleagues finished the report with the recommendation that the data collection should continue. While this project focuses on fatigue and environmental factors, other FAA Aviation Maintenance and Inspection Human Factors research efforts are collecting and studying error data. Ultimately, the data related to fatigue and workplace conditions shall be correlated with data related to error.

2.0 PHASE 2 DATA COLLECTION

Phase 1 showed that the data collection tools were dependable and accurate. Phase 1 activity collected the data in a very temperate climate, mostly with fixed indoor work. The current phase of the work sought to collect hot weather data (Johnson, et al 2001). The team focused data collection on airlines in the Southeast and the Southwest from early July through September. The team sought the jobs that were in the environment including line maintenance, unscheduled nighttime repairs on the ramp, and heavy maintenance in large hangars.

The hardware data collection was supplemented with a questionnaire that included not only those who wore equipment but also numerous other volunteers throughout the maintenance organization

Table 1 shows the timetable, location, number of shifts and number of volunteers that participated in this extensive data collection phase. The Houston data represents two locations of one company. When appropriate, the data is reported to represent 4 locations. At other times, the Houston data was collapsed to represent one company.

Table 1: Data Collection Timetable, Location, and Participants

Dates	Location	Shifts	Participants	Questionnaires
June	Atlanta	4	24	71
July	Dallas	3	22	70
August	Houston	3	21	27
September	Houston	2	23	331

3.0 DATA ANALYSIS AND RESULTS

Perhaps the most important finding in this large data collection effort is the fact that the airlines were, in almost all cases, statistically identical, reported at the $p<.05$ level. This is important because the data permit us to characterize working conditions and rest patterns as “industry-representative” rather than as specific to a location or to an airline. The research did show some statistically significant differences between shifts, some age groups, and other factors that shall be reported.

3.1 Sleep Data

The Actiwatch accelerometer can measure many sleep factors but the two sleep periods of interest are the actual sleep and the assumed sleep. The Actiwatch software calculates the “Actual Sleep”. This is based on measurement of inactivity of the wearer and is the very best measure of actual sleep. “Assumed sleep” is nearly equivalent to time in bed. It is based on a number of possible measures. The wearer can press an electronic marker, located on the watch, when they go to bed and when they wake up. Another method is to keep a written sleep log. A third method, the one used in this study, is for the researcher to study each Actiwatch chart and mark the period where relative inactivity commences (to bed) and activity resumes (up from bed). For this study, the researcher confirmed these assumed sleep markers with the participants. The data reported here is “Actual Sleep.” The Actiwatch consistently measures it and, thus, it is the most reliable data available. The “Assumed Sleep” was, on the average, about 50 minutes higher than the “Actual Sleep.”

The airlines are statistically identical with respect to sleep duration. The average sleep for aviation maintenance personnel is 5 hours. There was no significant sleep difference based on age groups. Table 2 shows descriptive sleep data across all shifts represented in this study.

Table 2: Summary of Sleep Data

Shift	N(Number)	Minimum	Maximum	Mean
Day	30	3:24	6:38	5:06
Afternoon	19	2:40*	6:31	5:04
Grave	12	4:01	6:09	5:00
All	65	2:40	7:36	5:05

*Confirmed with participant when analyzing sleep data on outbreifing

3.2 Temperature Data

The Mini-Logger collected Temperature, Sound Pressure, and Light data. The equipment records an average reading every two minutes, thus the amount of data can be overwhelming. Data was transferred from the Mini-Logger to the SPSS statistical program for analysis.

This was a warm weather study conducted in the Southeast and Southwest during the summer. The highest recorded temperature during the study was 130F (54^{o}C+). That is not surprising since the US National Weather Service reported temperatures in Texas during the data collection period in excess of 110F (43C+). Table 3 shows temperature distribution by location by shift.

Table 3: Temperature Ranges by Shift and Work Area

Temperature Data	N	Mean ^{0}F – ^{0}C	Standard Deviation ^{0}F – ^{0}C
Overall	49	86 - 30	4.9 – 2.7
Hangar	37	86 - 30	5.3 – 2.9
Line	12	84 - 29	3.2 – 1.8
Day	22	87 - 31	6.5 – 3.6
Afternoon	15	86 - 30	2.9 – 1.6
Grave	12	84 - 29	2.4 – 1.3

3.3 Sound Pressure Data

Sound, measured in Decibels (dBA), was statistically the same across all airlines. The average level was 67 dBA. As one might expect, there is significantly less noise on the Graveyard shift with an average dBA level of 59 across the carriers. Additional analysis indicated that about two thirds of the sound readings were between 41dBA and 93 dBA. The afternoon shift experienced the highest sound levels, but there was no statistical or practical difference between day and afternoon.

3.4 Light Level Data

The light data was measured in lumens per square meter, called a lx (lx). The sensor emerges from the Mini-Logger with the light-sensing probe. It measures the amount of light (illumination) on the person rather than the amount of light on the work. In most cases the measurement on the work or on the person is similar. However, in reduced light situations, when a flashlight or other directed light is used the measurement may be misleading. There are also times, in full ambient light, when the maintenance worker must look inside of a cowling or other such area where light is greatly reduced. The Mini-Logger does not account for that situation. For that reason, these data are more powerful in conjunction with responses from the questionnaire, reported in Section 3.5. The data aligned with the reports of Dr. Bosley (1999) and Thackray (1993).

Table 4 shows the industry average light and the median light (the reading in the very middle of all the data). The table shows the break out by number of participants (n), shift, and work area. Overall, there was a considerable range, most of which is below recommendation as discussed in Section 3.5.2.2.

Table 4: Light Data Across Shifts and Work Areas

Light Data (lx)	N	Mean	Median
Overall	53	692	266
Hangar	38	578	156
Line	15	979	783
Day Shift	26	649	236
Afternoon Shift	15	1182	758
Grave Shift	12	172	103

3.5 Questionnaire Data

The research team distributed a 41-item questionnaire to maintenance personnel at four different airports around the southern United States. A total of 499 personnel completed and returned the questionnaires. The items on the questionnaire served to gather basic demographic information, information about personal habits and information about fatigue and alertness in the workplace. The questionnaire was successful in obtaining a broad and diverse cross section of airline maintenance personnel. The Phase Report (Johnson, et al., 2001) contains extensive detail on the questionnaire data.

3.5.1 Demographics

3.5.1.1 Roles, Age, Job Experience and Shift

The questionnaire was distributed to maintenance personnel serving in a variety of roles. Many of the respondents (46.1%) work in the "Airframe" capacity. A substantial portion of respondents (41.7%) fell in the 36 – 45 year old age bracket. The 26 – 35 year old bracket was second in size, capturing 29.7% of the respondents. There were very few respondents fewer than 25 years old or over 66 years old, with each of those brackets containing 2.6% and .4% of the respondents, respectively. Results indicate that members of the sample have a wide range of time on the job, with the bulk of the participants (37.7%) having between 10 and 14 years of experience. Individuals with less than 5 years of experience and with over 20 years of experience comprise a reasonable amount of the sample. Regarding shifts, all three shifts are in the sample with the bulk of participants (43%) working the day shift.

3.5.2 Sleep, Fatigue/Alertness, and Lighting

The questionnaire collected a considerable amount of information from each of the participants, including information about eating habits and feelings about work. The discussion in this report shall focus primarily on fatigue and alertness issues. In total, six separate items addressed the issues of sleep and fatigue/alertness on the job. Two other items addressing lighting adequacy, may be indirectly related to fatigue and alertness (Human Factors Guide, 1998). The data were examined across age group and shift worked to determine if response patterns differed systematically as a function of these grouping variables

3.5.2.1 Sleep and Fatigue/Alertness

For the most part, the response patterns to these items are rather predictable. For example, most of the respondents indicated that they feel most alert at the beginning of their work shift. About 30% of participants indicated that fatigue is a factor that negatively impacts their job performance.

Sixty percent of the respondents reported that they slept over 6 hours the previous night. However, the Actiwatch data shows accurately that the average sleep was about 5 hours. The Actiwatch data also indicates that about 67% of the participants slept on average between 4.2 and 6 hours. This difference in data, between Actiwatch and self-report, may be attributable to numerous factors. First, the respondents may be over reporting their sleep slightly. Secondly, the Actiwatch is very accurate and does not count the initial "tossing and turning" as sleep. Thus there is a likely difference between the time in bed versus the actual sleep time. In any case, the combination of the Actiwatch data with this questionnaire and with the previous fatigue questionnaire (Sian and Watson, 1998) strongly suggests that maintenance personnel are not fully aware of their sleep duration and the possible fatigue that may result.

3.5.2.2 Adequacy of Lighting

The questionnaire addressed the issue of adequate lighting. Questionnaire responses indicated that about 45% of participants work under inadequate illuminated conditions "Frequently" or more often, and that over 40% of participants felt that inadequate lighting negatively impacted their job performance. This data is in agreement with the data from the Mini-Logger. In this case the questionnaire data is likely to be more accurate than the Mini-Logger measurements, because it is based on the actual perception of the workers.

In summary, many participants feel that lighting conditions are less than optimal for a substantial portion of the time that they are working. Furthermore, a substantial number of participants felt that poor lighting does have a negative impact on their job performance. Due to the way in which this questionnaire item was phrased, it is impossible to know *how* inadequate lighting negatively impacts performance (i.e. reduction of quality, reduction of quantity, etc.), only that many participants *perceive* a negative impact. But this information can be very telling as the participants are experts at what they do and the data indicate that lighting is not adequate in many circumstances and that this causes problems on the job.

4.0 RECOMMENDATIONS

This section shall shows examples of the areas where the observed data are outside of the recommended limits. The Phase Report (Johnson, et al., 2001) discusses these recommendations in greater detail.

4.1 Sleep

Table 5 shows summary Actiwatch data and the recommendations for sleep. Most researchers advocate an average sleep requirement for adults is 7.5-8.0 hours per day.

Table 5: Actual Sleep vs. Recommended Sleep

Mean Overall Sleep Experienced by Participants	**Recommended Levels by Carskadon & Dement as cited by Battelle, 1998**
Mean: 5:06 sleep per night* *Assumed sleep was nearly 6 hours.	7:30 to 8:00 sleep per night

The data clearly shows that airline maintenance personnel sleep about 5 hours per day. All sleep experts agree that 5 hours is not enough sleep (Battelle, 1998, Gallup, 1997). The experts generally agree that the population of maintenance personnel is acquiring a daily "sleep debt" of at least 2 hours. Since the Actiwatch was worn 7 days a week for the two-week data collection period it does not appear that maintenance personnel are repaying the sleep debt. However, the questionnaire data reported in Section 3.1 does not reflect a population that perceives chronic fatigue or tiredness. The data collected from the Actiwatch strongly suggests that the population of aviation maintenance workers has a sleep deficiency problem and has not yet acknowledged that potential problem. The only caution that must be added here is that "Assumed Sleep" as discussed in Section 3.1 is about 50 minutes greater than the actual measured sleep. In either case, the sleep amount is below recommendations.

Changing the culture of aviation maintenance personnel to sleep more hours is likely to be difficult. Education may be the only way to accomplish this cultural change. During the data collection the research team observed that the personnel who wore the Actiwatch became sensitized to their sleep habits. It is likely that airline maintenance personnel are simply unaware of their sleep habits versus the recommended sleep amounts. Airlines could use equipment like Actiwatches to help technicians to understand their sleep habits and form improved habits if necessary. While this is only speculation, the productivity return on investment would quickly justify the cost of the equipment, administration personnel, and training. Phase 3 of this research program shall try to determine the extent of error and associated cost can be based on worker fatigue.

Another possible manner to motivate personnel, with respect to sleep, is to initiate an education campaign related to "Fitness for Duty." While many associate "Fitness for Duty" with alcohol or drugs it can also apply to sleep. Of course, sleep deprivation is not as easy to measure as alcohol or drugs.

Instead of changing the culture regarding sleep another approach is to make personnel aware of the signs of fatigue. If personnel can recognize fatigue they can help one another to avoid the inevitable performance degradation and potential error. During 2000, the Air Transport Association (ATA, 2000) published the *Alertness Management Guide*. The document was designed for flight crews but has applicability to everyone. The ATA guide offers quick explanations of the importance of sleep as a vital physical need. It strongly endorses the importance of the 8-hour sleep requirement and the “debt” that accumulates. Among the many recommendations offered are such actions as the following: Minimize sleep loss; alter habits to acquire necessary sleep; create the right environment for sleep and; the effect of age, alcohol, diet, and exercise on sleep. This type of guideline and education program should be implemented for maintenance personnel. The labor unions, companies, or the FAA through this research program should foster such informational activity.

4.2 Temperature

Table 6 shows summary Mini-Logger data and the recommendations for temperature. The summer temperatures in the Southeastern and Southwestern United States are quite high and certainly affect work performance and promote fatigue. Sixty-nine percent of the questionnaire respondents said that high temperatures affect their job performance. That was rated higher than any other factor. The temperatures reported for this shortened report have not factored in the high humidity levels. The danger is that high temperature tells only a portion of the story.

Table 6: Actual Temperature vs. Recommended Temperature

Mean Overall Temperature Experienced by Participants	**Recommended Levels by FAA Human Factors Guide for Aviation Maintenance**
86°F (35°C)	Thermal Comfort Index Chart must be used.

The companies that participated in the study followed most of the good practices related to working in high temperature conditions. Water and ice must be, and were, quite plentiful. In all cases there were water jugs, ice, and large and clean drinking cups. In most cases the containers were located close to the work areas making it very convenient for works to get a drink of water. The questionnaire data confirm that workers were likely properly hydrated. Ninety-seven percent of the respondents said that water was readily accessible at work. Eighty percent of the respondents had water at least 3 times each day, while 39% reported at least 5 glasses of water each day.

It is valuable to move the air, even when the air is an elevated temperature. Again, the research team observed numerous portable fans and portable air conditioning systems. For the hangar work all of the aircraft interiors were cooled adequately. The challenges occur when unscheduled maintenance arises and workers must access elevated tail sections, cargo bins, avionics compartments, and similar confined spaces. It is critical that workers maintain a focus not only on the job task but also on the temperature of the work environment.

The extreme high temperatures were observed on the flight line. The combination of high ambient temperatures on the hot ramp with hot aircraft and ground equipment presents a very high temperature risk. The team observed an awareness of this high temperature challenge. The means of mitigating such conditions include adequate staffing, reasonable scheduling of activity, proper pacing in high temperature conditions, plenty of water, and adequate rest throughout the work shift.

4.3 Sound Pressure

The questionnaire data rated "Noise" as the third highest (58%) environmental factor affecting job performance. The temperature and humidity were ranked 1 and 2, respectively. Noise may be even more difficult to control than temperature/humidity. High sound is an unavoidable by-product of turbine engines and industrial repair equipment. However, the industry can and does take steps to be sure that the high sound levels do not injure workers or completely stifle safe and effective communication.

The mean overall sound experienced by most (67%)participants was 67 dBA +/- 26, within the OHSA limits. Since the volunteers wore the Mini-Loggers and Actiwatches without supervision, it is not possible to know when hearing protection was worn thus the sound pressure measurements are nor particularly valuable. Research observations indicate that ramp personnel, in particular, wore hearing protection as required. Future analyses shall assess duration of sound pressure as well as levels.

Recommendations regarding sound and noise control are available in the *Human Factors Guide for Aviation Maintenance*. *The Guide* stresses the importance of determining alternatives for verbal communication in high ambient noise environments. *The Guide* also offers guidance for workplace design to isolate and protect workers from harmful noise.

4.4 Light Level

Forty-two percent of the questionnaire respondents rated inadequate lighting as a factor that affects job performance. That factor was number 4 following temperature, humidity, and noise. Nearly 50% of the respondents indicated that they worked in inadequate lighting "Frequently, Very Frequently, or Always." There appears to be a lighting problem as reported by the respondents.

The light data, from the Mini-Loggers confirmed the opinion of the questionnaire respondents. The overall mean of 692 appears to be on the low side of the recommendation shown in the table. However, as mentioned in Section 3.4, the data had an unusual statistical distribution. The middle (Median) amount of lux was 266, which is considerable below the recommendation. This situation is caused by the fact that the majority of participants had very low average light readings.

The "bottom line" is that the data show that, generally, there is not enough light in the maintenance workplace. Ambient illumination, as measured at the front pocket of the Mini-Logger wearer is insufficient for most maintenance and inspection work. Table 7 shows summary Mini-Logger data and the recommendations for light levels.

Table 7: Actual Light Levels vs. Recommended Light Levels

Mean Overall Light Experienced by Participants	Recommended Levels by FAA Human Factors Guide for Aviation Maintenance
Mean: 692 lx Median: 266 lx	Between 750 – 1000 lx

Numerous Human Factors studies have lamented the inadequate lighting conditions in the airline maintenance environment. The data confirms past studies. The measured data showed that ambient illumination is low and inadequate. The light probes could not account for portable directional lighting systems that are often available. However, the 500 questionnaire respondents, most likely, considered all lighting situations as 40% rated the lighting to be inadequate, as discussed in Section 3.5.2.

When one searches the FAA Maintenance Human Factors Website on the word "lighting" there are 417 hits. There are 133 hits on "illumination", 43 on "flashlight," and 1 on "torch" for the British readers of this report. The *Human Factors Guide* offers checklists to assess the workplace for proper illumination. The *Guide* also leads to references on lighting such as the *IES lighting handbook-Application volume* (IES, 1987).

5.0 PHASE 3 PLANS

Phase 3 is the final phase of the data collection currently scheduled. The challenge in Phase 3 is to complete data collection and begin to map fatigue and workplace factors to incidents and accidents. In addition, this Phase has the goal to develop models to predict when the combination of fatigue and workplace factors is likely to result in human error. Finally, Phase 3 will create a stand-alone guidelines document that can be used to help maintenance personnel understand and address fatigue and other workplace factors within their control.

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